Studies on Inspection Technology of Welding Joints for Spent Fuel Dry Casks

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Japan Nuclear Energy Safety Organization (JNES) will perform a welding inspection of dry cask for the spent fuel which will be one of supporting activities on the regulatory body.

It has been clearly demonstrated in laboratory and field studies plus field experience with actual and simulated components that the stress corrosion cracking (SCC) of stainless steel could occur at salinity simulating typical cask environment. A SCC-resistant stainless steel would be used for a canister of a concrete cask. The regulatory body required a multi-layered dye penetrant test (PT) and an ultrasonic test (UT) at a canister closure weld inspection of the canister because of difficulty of a radiographic inspection. Therefore applicability of the PT and the UT will be confirmed at the canister closure weld inspection of the canister, which is expected to be high humidity and high temperature at the welding and high temperature at the inspection, for new type of the stainless steel. JNES has planned and been performing experiments for welding inspection technology and procedures. The studies from 2005 to 2009 consist of a welding technology, material property test of canister body and welding portion, applicability experiments of the multi-layered PT and the UT using test peaces, welding technology test and welding inspection test by mock-up model and an evaluation of a critical flaw size at welding joints.

Analyses results of canister temperatures are shown in Fig 1. These results were used for an establishment of welding experiment condition. This paper describes the experiment plan and results from studies in 2005 and 2006 which were material property test of canister body and preliminary experiments of the PT and the UT.

Studies on Inspection Technology of Welding for Spent Fuel Dry Casks

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1. Abstract

In Japan, spent fuels will be reprocessed as recyclable energy resource at a reprocessing plant, which will start the operation in 2008. Since the amount of spent fuels from operating nuclear power plants is estimated to exceed the reprocessing plant capacity, a license of the commencement of independent interim storage facility (ISF) for spent fuels operation in 2010 is now under application and utilities are planning another next ISF. Japan Nuclear Energy Safety Organization (JNES) will perform a welding inspection of dry cask for the spent fuel in accordance with the related laws and regulations.

It has been clearly demonstrated in laboratory and field studies as well as field experients with actual or simulated components that the stress corrosion cracking (SCC) of austenitic stainless steel could occur at salinity simulating cast condition. Therefore, a SCC-resistant austenitic stainless steel would be used for a canister of a concrete cask. The regulatory body required a multi-layered dye penetrant test (PT) and an ultrasonic test (UT) at a cask closure weld inspection of the canister because of unavailability of a radiographic inspection. Before an actual inspection, an applicability of the PT and the UT should be confirmed at the cask closure weld inspection of the canister, which is expected to be high humidity and high temperature at the welding and high temperature at the inspection, for new type of the austenitic stainless steel. JNES has planed and been performing experiments for welding inspection technology and procedures. The studies from 2005 to 2009 consist of a welding technology, material property test of cask body and welding portion, applicability experiments of the multi-layered PT and the UT using test peaces, welding technology test and welding inspection test by mock-up model and an evaluation of a critical flaw size at welding.

2. Project Outline

(1) Materials to be used

The materials to be used for metallic cask in domestic spent fuel ISF have been specified in the standards of the metallic cask society based on a survey of materials of the existing domestic transportation and storage casks. On the other hand, for the canister used for concrete cask, the foreign canister materials (stainless steels) with sufficient experiences would not be used due to a concern about corrosion resistance under the domestic condition where onshore siting is expected. Therefore, as the materials for domestic canister, the following materials with enhanced resistance against SCC by sea saline particles will be used, although no utilizing experience of them has been obtained in existing foreign canister.

- ASME SA-240 S31260

  This steel is an enhanced corrosion resistant duplex stainless steel consisting of austenite/ferrite. The material contains extremely low C, high Cr, and high Mo and has excellent resistance against local corrosion attack (i.e., pitting corrosion, crevice corrosion, SCC, etc.), as well as excellent acid resistance against various acids.

- ASME SA240 S31254

  This steel is a super stainless steel with extremely improved chloride corrosion resistance and acid resistance by adding N and Cu into high Cr – high Mo steel.

3. Material Property Test

(1) Materials for Test

The specimens were prepared for the material property test of the base material used for the closure of canister seal vessel, the welding technology test for canister closure weld, and the basic test for its ultrasonic test (UT). Table 1 shows major material properties and specimens and table 2 summarizes the types and quantity of the required specimens, respectively

Table 1. Material Properties of Specimen

Item	ASME SA240S31260	ASME SA240 S31254
Tensile Strength MPa	≥690	≥650
Proof Stress MPa	≥485	≥300
Elongation %	≥20	≥35
Hardness HB	≤290	≤223
Impact Testing Temperature °C	Lowest Service Temperature (-20°C)	Lowest Service Temperature (-20°C)
Lateral Bulging mm	≥1.00	≥1.00
Impact Value J/cm^2	≥125	≥125

Table 2. Types and Quantity of Specimens

Item	Material				
	ASME SA240 S31260	ASME SA240 S31254		ASME SA182 F304	
Thickness	50 mm	50 mm	20 mm	200 mm	50 mm
Dimensions (L×W) mm	1000 × 500	2300 × 1550	2000 × 1000	200 × 200	2000 × 600
Quantity	1	1	1	1	1
Fabrication Method	Hot Rolling	Hot Rolling	Hot Rolling	Forging or Hot Rolling	Hot Rolling
Remarks (Purpose)	• Material Property Test • Welding Technology Test • UT Detection Capability Test	• Material Property Test • Welding Technology Test • UT Detection Capability Test	• Material Property Test	• UT Detection Capability Test	• Welding Technology Test

(2) Material Property Testing

We considered that the following basic material data should be acquired.

1) Chemical composition (MIL sheet based): To confirm that it has complied with the standard.

2) Tensile properties: To confirme that Sy and Su at high and low temperature to calculate S (or Sm) required in the design are on the safety side.

3) Concrete cask for interim storage: Toughness as a special requirement for canister was confirmed.

4) Thermal expansion coefficient: To confirme that the thermal expansion coefficient meet the value required in the design.

5) Modulus of elasticity: Like as the thermal expansion coefficient, to confirm that the modulus of elasticity meet the value required in the design.

Table 3 shows the items of material property test.

Table 3. Items of Material Property Test

Test Item	Checked Contents/ Condition	Quantity for Testing			Remarks
		ASME SA240S31260	ASME SA240 S31254		
		50 mm Plate	20 mm Plate	50 mm Plate	
Chemical Composition	Standard Composition	-	-	-	Confirmation of base material with its MIL sheet
Macroscopic / Microscopic Structure and Hardness	Macroscopic/ Microscopic Structure	1	1	1	Hardness was checked only for weld.
Tensile Testing (including σ-ε) (Weld was inspected when the welding conditions were determined for joint welding alone.)	-30	2	2	2	Only one stress-strain graph
	0	2	2	2	Only one stress-strain graph
	Room Temperature	2	2	2	Only one stress-strain graph
	75°C	2	2	2	Only one stress-strain graph
	100°C	2	2	2	Only one stress-strain graph
	150°C	2	2	2	Only one stress-strain graph
	200°C	2	2	2	Only one stress-strain graph
	250°C	2	2	2	Only one stress-strain graph
	300°C	2	2	2	Only one stress-strain graph
Impact Testing (Sharpy V)	-20°C	3	3	3	
	Other 5 Temperatures	15 (3 pieces× 5 temperatures)	15 (3 pieces× 5 temperatures)	15 (3 pieces× 5 temperatures)	
Fracture Test	-20°C	3	-	3	
Linear Expansion/Thermal Diffusivity		1	1	1	One specimen, 3 temperatures.
Thermal Conductivity		1	1	1	Same as the above.
Modulus of Elasticity		1	1	1	Same as the above. But, at 11 temperatures.
Modulus of Rigidity		1	1	1	Same as the above. At 3 temperatures.
Poisson's Ratio		1	1	1	Same as the above.

(3) Results of Material Property Test

1) For ASME SA240 S31260 specimens with thickness of 50 mm, it was confirmed that their chemical composition, metallic texture, and mechanical properties (strength, ductility and toughness) complied with the criteria specified in the Guidelines and Rules for Spent Fuel Storage Facilities of the Japan Society of Mechanical Engineers. (See Figs 1 and 2)

2) For ASME SA240 S31254 specimens with thickness of 50 mm, although their chemical composition, metallic texture, and toughness had no any problems, their strength was below the design strength of ASME (Sy, Su), especially at higher temperature. (See Figs 3 and 4)

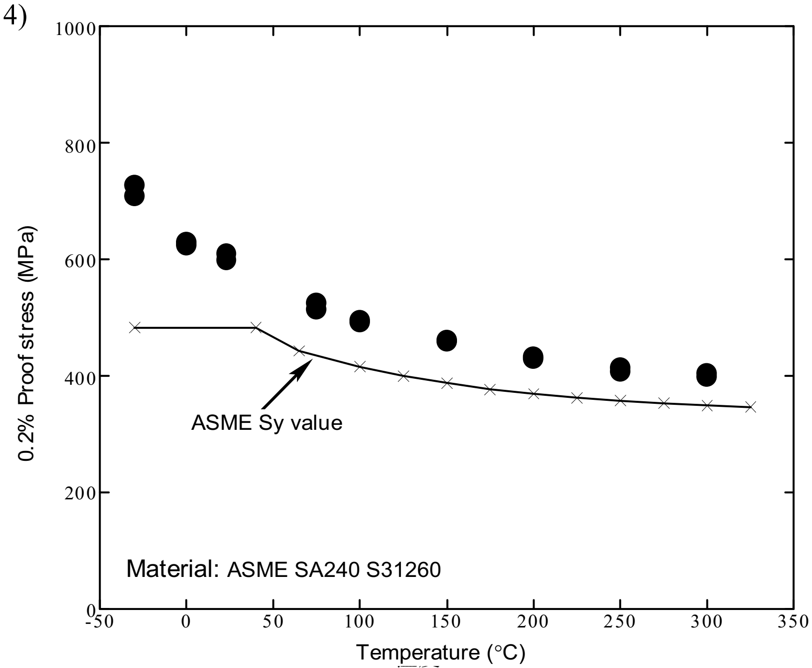


Figure 1. Comparison between 0.2% Proof Stress and ASME Sy Value of ASME SA240 S31260

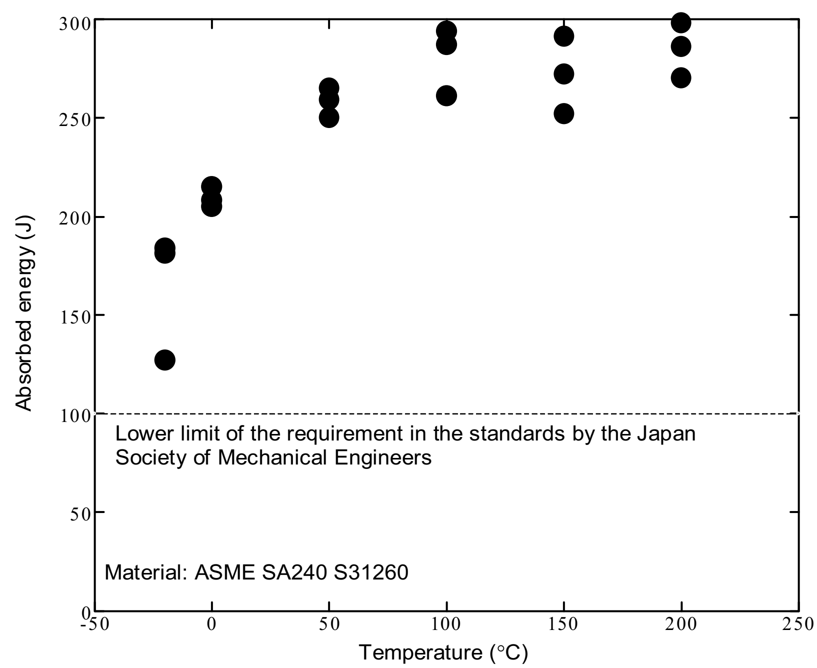


Figure 2. Dependence of Absorption Energy of ASME SA240 S31260 on Temperature

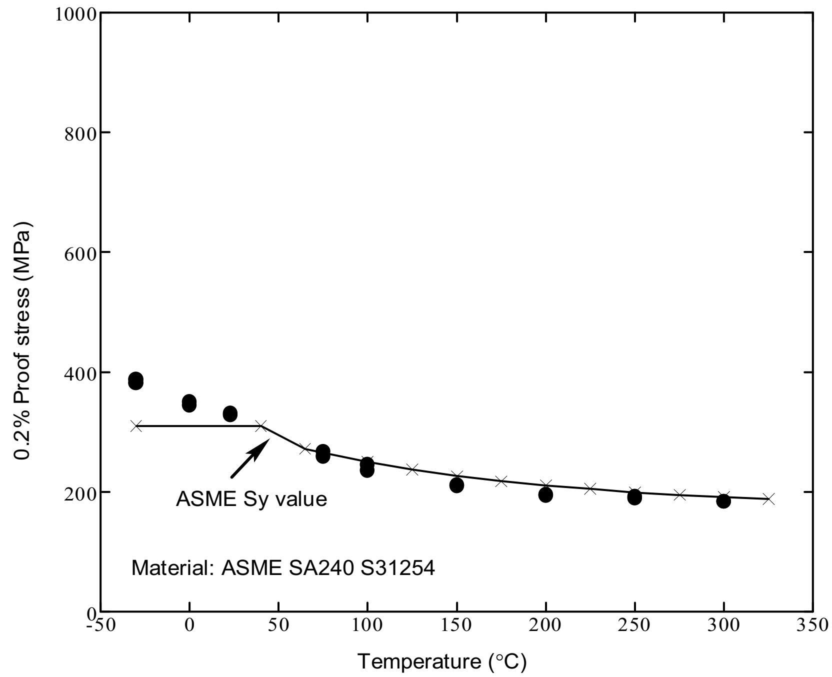


Figure 3. Comparison between Test Results and ASME Sy Value of ASME SA240 S31254 (Thickness 50 mm)

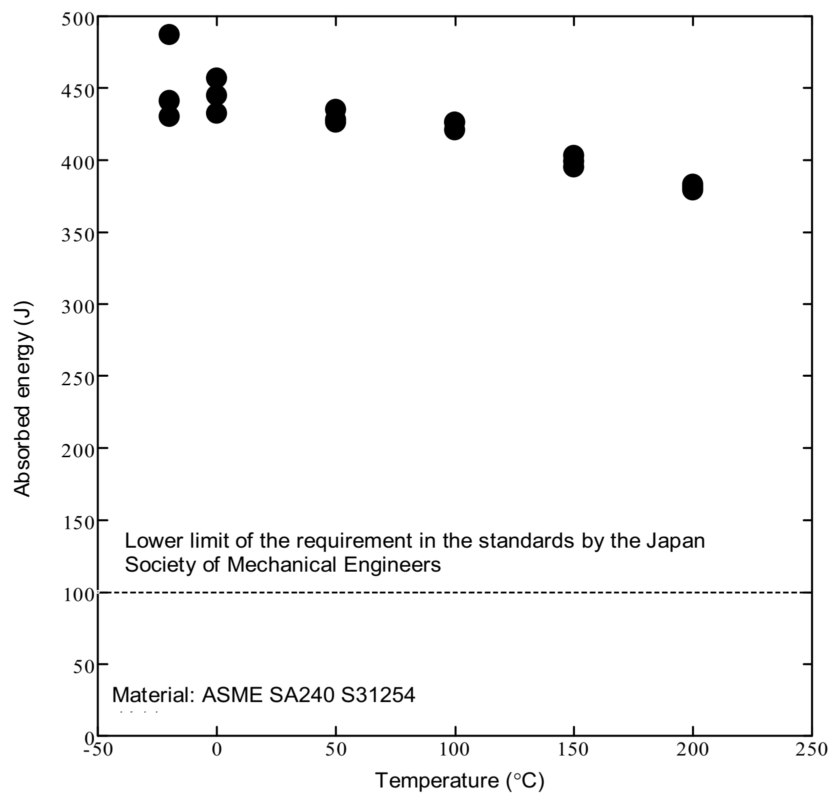


Figure 4. Dependence of Absorption Energy of ASME SA240 S31254 on Temperature

4. Welding Technology Test

The requirements for canister closure weld are that the section complies with mechanical criteria, intact weld can be obtained, and toughness of the closure can be assured. Thus, we carried out multi-layered welding under the condition simulating actual environmental condition to demonstrate that intact weld could be assured and sufficient mechanical properties could be attained. As the test materials, we used ASME SA240 S31260 and ASME SA182 F304 specimens for the primary closure welds of canister and carried out the welding technology test under the condition that steam flows out from groove gap when one-side welding without backing strip. Thereby, we tried to characterize surface oxidation and the occurrence of blow holes and to obtain the information about the range of practicable welding conditions. Welding was carried out with GTAW (TIG welding) method.

(1) Test Conditions

No. of Specimen	Test Parameters (number such as 1 to 3 indicates the conditions.)						
	Steam Quantity		Boric Acid of Groove	Washing of Groove	Back-Seal Gas	Welding Shield Gas	Groove Gap
	Boric Acid	Level					
1)	No	1	No	No	No	1	2
2)	No	2	No	No	No	1	2
3)	No	3	No	No	No	1	2
4)	Yes	1	3000 ppm as B	Yes	No	1	2
5)	Yes	2	3000 ppm as B	Yes	No	1	2
6)	Yes	3	3000 ppm as B	Yes	No	1	2
7)	Yes	2	3000 ppm as B	No	No	1	2
8)	Yes	2	3000 ppm as B	Yes	Yes	1	2
9)	Yes	2	3000 ppm as B	Yes	No	1	3
10)	Yes	2	3000 ppm as B	Yes	No	1	1

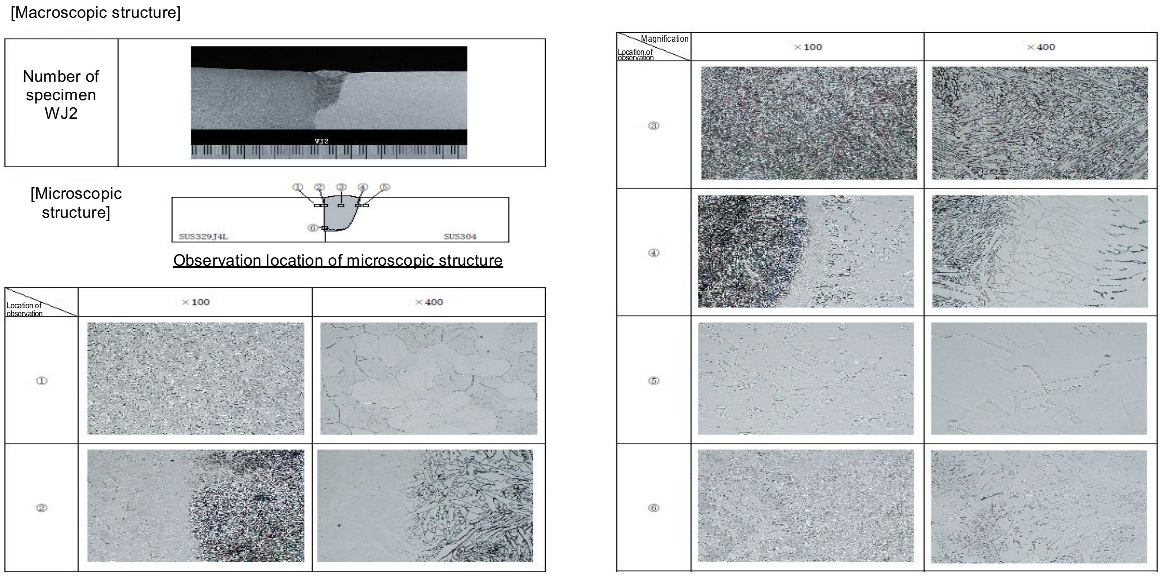
Where, steam level was as follows (water temperature control): 1: 70°C
2: 85°C
3: 100°C

Groove gap was as follows: 1: 0.8 mm
2: 1.8 mm
3: 2.8 mm

(3) Results of Welding Technology Test

1) The test result demonstrated that ASME SA240 S31260 and ASME SA182 F304 could be welded each other with GTAW (TIG welding) method and almost intact weld could be obtained.

2) In the non-destructive inspection during and after the welding process, PT procedure by first layer PT, last layer PT (and middle layer PT carried out for some specimens), and RT procedure revealed no flaw indication for all the specimens under the investigated 10 welding conditions. (See Fig 5)



Photographs 5. 3. 4-2 Macroscopic and Microscopic Structure of the Welded Joint of SUS329J4L/SUS304 (WJ2)

Figure 5. Macroscopic and Microscopic Structures of Welded Joint of ASME SA240 S31260/ASME SA182 F304

5. PT and UT Test

(1) Test Method

Although ASME SA240 S31260 and ASME SA240 S31254 investigated in this study are applied for some purposes such as the products contacting with seawater and the products for food industry, there are only few using experiences of them in other fields. Thus, ultrasonic transmission characteristics in them are unclear. Therefore, to investigate the applicability of UT test, we checked the fundamental ultrasonic characteristics including travelling velocity, attenuation, and anisotropy of ultrasonic wave. We figured out its temperature dependence in wide temperature range up to 120°C because the canister closure should be inspected with UT method not only at room temperature but also under the hot condition that spent fuels are contained in the canister.

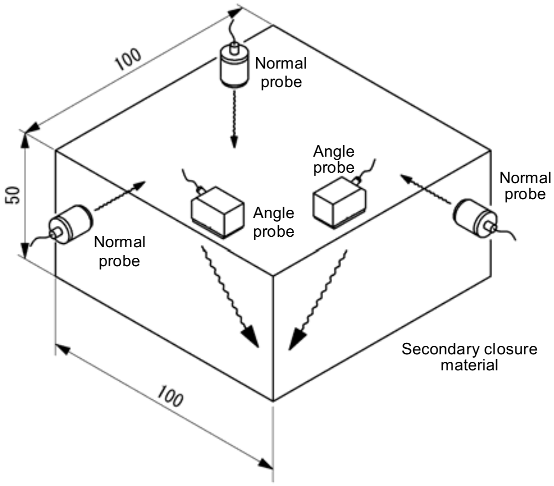


Figure 6. Transmission Test and Anisotropy Test for ASME SA240 S31260 and ASME SA240 S31254

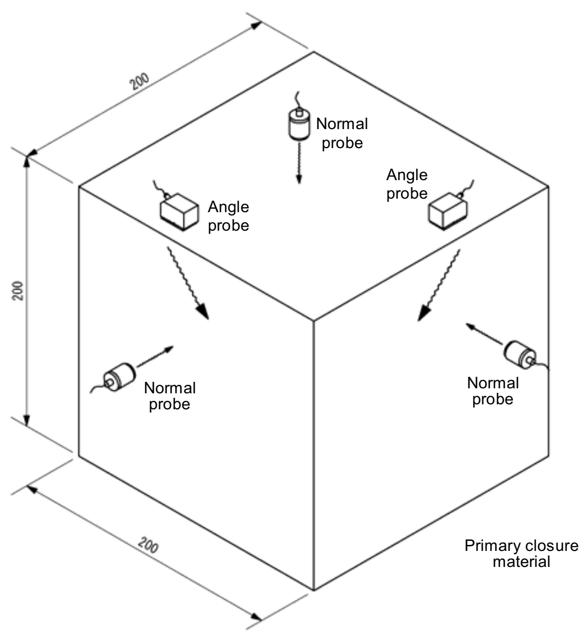


Figure 7. Transmission Test and Anisotropy Test for ASME SA182 F304

(2) Test Results

1) The ultrasonic attenuation in ASME SA240 S31260 and ASME SA240 S31254 may be slightly larger in the direction of plate thickness and may not show significant difference between the rolling direction and its perpendicular direction. In addition, attenuation coefficient tends to be slightly larger for 5MHz than that for 2MHz. On the other hand, it tends to become slightly smaller at higher temperature and its flaw detection capability may increase at higher temperature rather than at room temperature. When comparing the results with ones for standard ASME SA182 F304 material, while both the materials tend to show slightly higher attenuation coefficient than that of standard ASME SA182 F304 material, the difference may be considered as to be almost insignificant.

2) UT transmission characteristics in ASME SA240 S31260 and ASME SA240 S31254 may be equivalent to that of ASME SA182 F304 and therefore the UT method may be sufficiently applicable to the actual inspection.

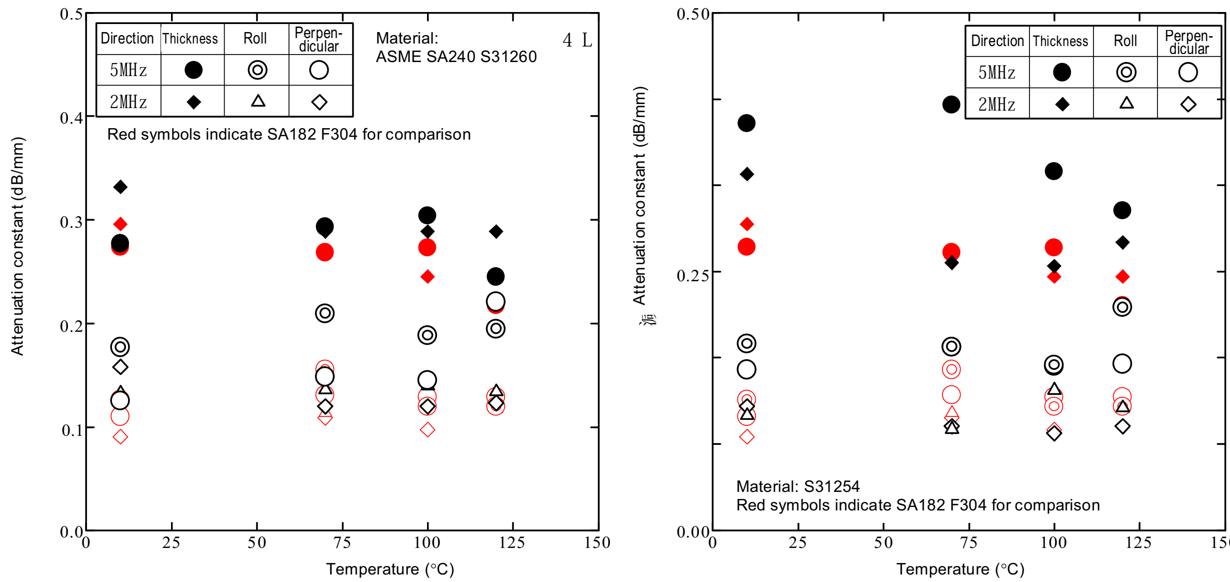


Figure 8. Anisotropy of ASME SA240 S31260 and ASME SA240 S31254
(comparison with ASME SA182 F304)

6. Conclusion

To establish the technical standards for welding, we carried out the following studies for canister materials to be used and on their welding process to be implemented in domestic ISF.

1) Confirmation of fundamental material properties
2) Investigation of welding method for the materials
3) Investigation of the inspection methods newly required for the weld

We could verify the material properties of SUS329J4L and ASME SA240 S31254 being the new materials used mainly for concrete cask, characterize their UT test capabilities, and demonstrate the weldability of former material.